

Chapter 3.2

Biomorphic Intelligence

Deploying Biotechnology in Architecture for Human Health and Wellbeing

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Ubiquitous computing enables us to decipher the Biosphere's anthropogenic dimension, what the authors call the Urbansphere (Pasquero, Poletto, 2020). This machinic perspective unveils a new post-anthropocentric reality, where the impact of artificial systems on the natural Biosphere is indeed global, but their agency is no longer entirely human.

In order to design the Urbansphere, it becomes therefore necessary to explore a protocol for the urbanisation of the non-human. In this chapter, it is called DeepGreen. In particular, with the development of DeepGreen, the authors and their team are testing the potential to bring at the core of architectural and urban design research the interdependence of non-human forms of digital and biological intelligence.

This is achieved by developing a new bio-computational design method and related workflow that enables pairing what is algorithmically drawn with what is biologically grown (Pasquero, Poletto, 2016; Figure 3.2.1). In other words, and more in detail, the chapter illustrates how GAN (Generative Adversarial Networks) algorithms (Radford et al., 2015) can be trained to “behave” like a *Physarum Polycephalum*, an unicellular organism endowed with surprising computational abilities and self-organising behaviours that have made it popular among scientists and engineers alike (Adamatzky, 2010; Figure 3.2.2). This novel methodology and related workflow is therefore called GAN_Physarum.

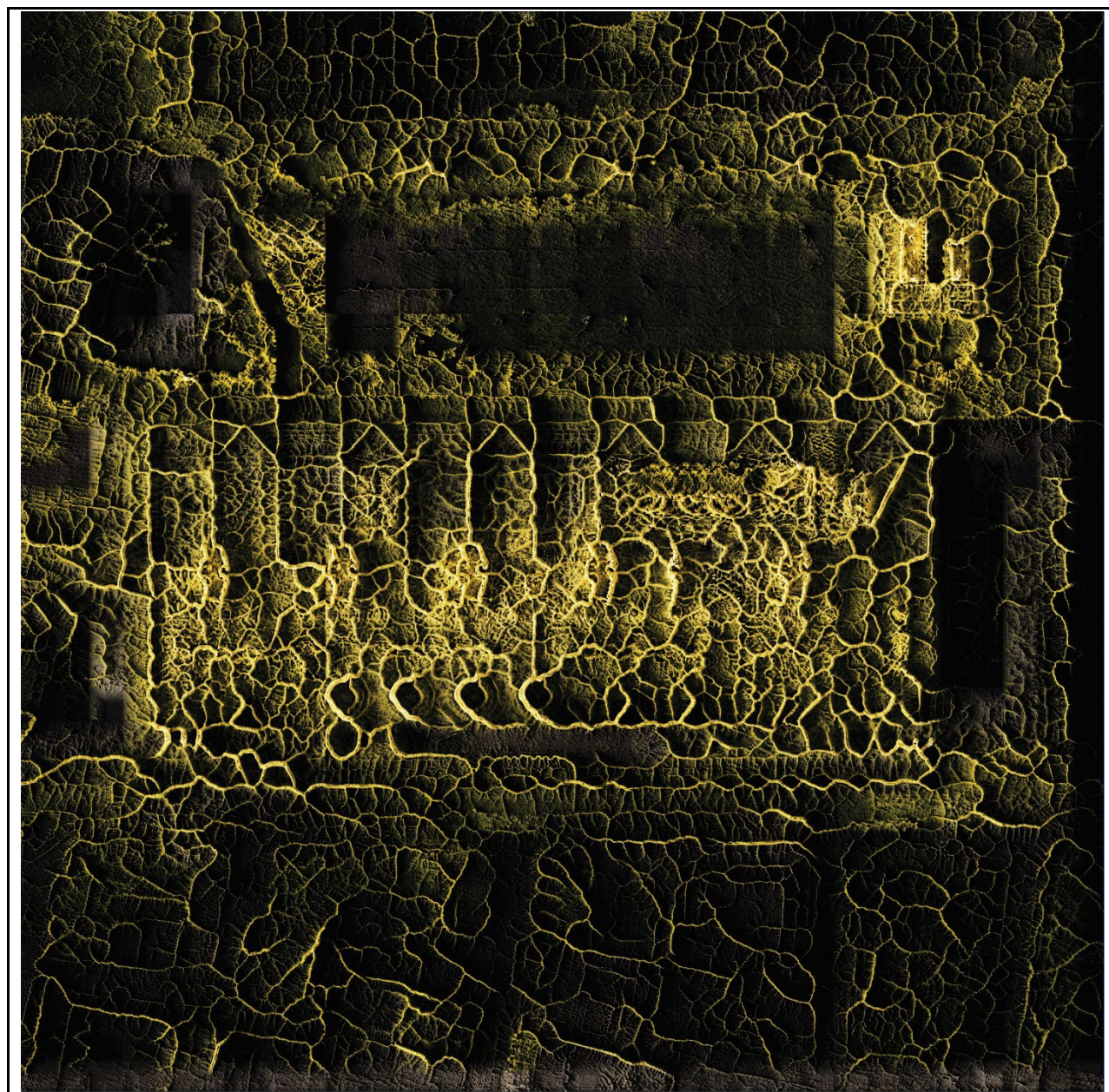


Figure 3.2.1 Translation of the Centre Pompidou in Paris by GAN_Physarum algorithm. 100 by 100 metre frame.

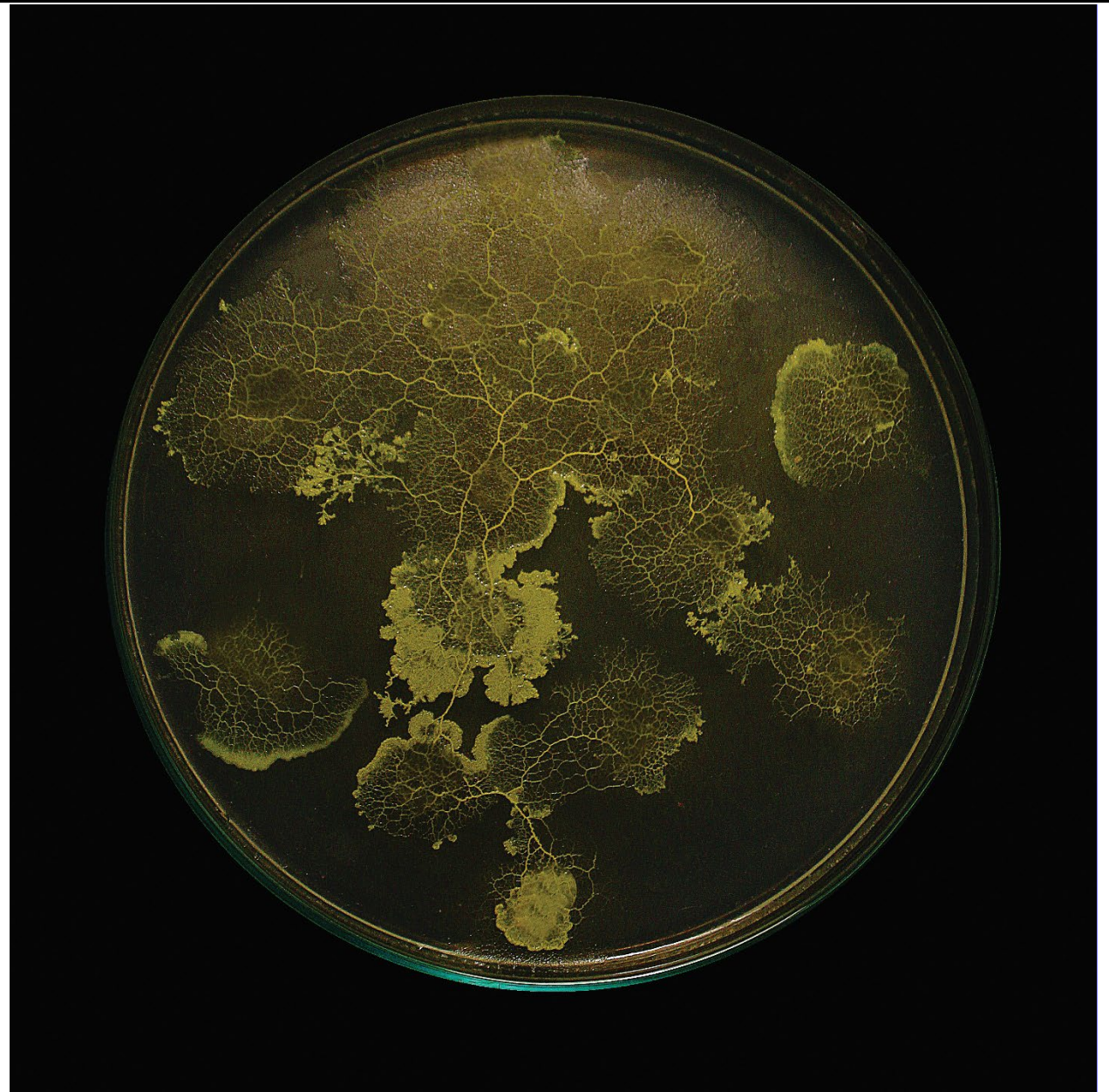


Figure 3.2.2 Physarum Polycephalum growing in a Petri dish. The image shows the plasmodium phase when the organism behaves as biological computer.

The trained GAN_Physarum is deployed as an urban design technique, to test the potential of Polycephalum intelligence in solving problems of urban re-metabolisation and in computing scenarios of urban morphogenesis within a non-human conceptual framework. Finally, this approach is taken one step further into actualised biotechnological architectures,

directly contributing to improved urban health and the emergence of new circular economies within the Urbansphere.

Developing a Bio-Digital Design Workflow

Learning how to interpret large remote sensing data sets from the unique perspective granted by GAN_Physarum, enables a deeper enquiry into the contemporary significance of traditional planning concepts such as zone, boundary, scale, typology and program.

This process introduces new spatial metrics to measure cities' self-sufficiency, valuing what economists call “externalities” towards other societal and ecological systems (Mazzuccato, 2017). A specific bio-computational design workflow generates consistent training datasets for GAN_Physarum, and this chapter illustrates the authors' efforts in that regard. The workflow includes four main levels of computation. Input data reading, biotic-abiotic analysis, network analysis and finally scenario modelling.

For the first-level analysis, advanced algorithmic design techniques are used in order to read large data sets from satellite, GIS and Digital Elevation Model sources (Pasquero, Poletto, 2017). Level 2 and 3 recognise and analyse the morphology of the city, the surrounding landscape and the resources' networks. The analysis produces density maps and path systems for several urban systems such as biomass, water collection, solar energy, community waste and so on. These maps become training datasets for GAN_Physarum.

Setting Up a Test Bed for DeepGreen

The chapter illustrates a number of applications of this approach to real case studies. In particular within the framework of ecoLogicStudio's ongoing cultural collaboration with the Centre Pompidou in Paris, with partner cities, within the framework of the United Nations Development Programme (UNDP innovation facility funding and City Experiment Fund) and with corporate

clients in the health and pharmaceutical industry. The aim of these case studies is twofold: to speculate on the significance of a non-human design framework on the re-conception of a heavily planned city such as Paris, and consequently to provide local communities, cities and governments at large with the most advanced toolset to reprogram global cities for a safer and healthier post-pandemic world.

Ultimately with the integrated use of remote sensing, big data analysis and Artificial Intelligence, DeepGreen can be deployed to assess urban vulnerabilities and find specific urban design solutions to achieve immediate and long-lasting impact. Through these case studies, the authors speculate on the possibility for a general applicability of the DeepGreen protocol, its scalability and possible widespread adoption. This speculation provides a critical assessment of the current paradigm of urban “green” planning and the conceptual and practical significance of urban re-greening in the current, crisis-ridden, post-anthropocentric reality.

Training and Testing GAN_Physarum

cycleGAN algorithms belong to the class of machine learning frameworks (Zhu et al., 2017). They involve an automatic unsupervised training of image-to-image translation models without paired examples. In this case, the domain of sources images and target images refer to the slices of two actual input-images that belong to two different domains, the urban and the biological. In other words, cycleGAN algorithms provide a means to train a digital urban model to map the behaviour of a living biological one based on visual clues, that is, through the manipulation of a large number of images of both models.

cycleGAN algorithms are deployed at level 4 of the overall DeepGreen workflow and the process can be further divided in four phases for clearer illustration.

The first phase describes the preparation of the input images deployed to train GAN_Physarum. The second phase is the training of the algorithm based on these input datasets. The model is trained to detect the urban morphology of case study cities and the biological

growth patterns of *Physarum Polycephalum*. During training the algorithm typically runs 200 epochs, or iterations, over which it self-improves.

At this stage, the models are sufficient for generating plausible slices in the target domain but are not translations of the input slice. This occurs in the third phase, the testing phase, during which the algorithm translates the bio-computational patterns onto the case study city.

In the fourth phase all resultant tiles are recombined, and the final output image is recreated. This can produce true colour satellite visions of the case study, its urban morphology and several testing scenarios for the integration of biotic and abiotic systems within the urban landscape (Figure 3.2.3).



Figure 3.2.3 Application of GAN_Physarum algorithm and DeepGreen protocol to Guatemala City. The images show the redevelopment of the local/municipal waste collection networks into a new bio-digestive urban system. Image 1 is algorithmically computed from GIS map, satellite map and DEM model analysis by means of minimal path algorithm. The analysis also takes into account the result of the local waste collection analysis. Image 2 reinterprets the municipal waste collection networks of Guatemala City using the GAN_Physarum algorithm. Image 3 illustrates the redefined urban morphology and the materiality of two overlapping systems: local to municipal waste collection networks and the vegetation network in the city of Guatemala City. Algorithm training is based on *Physarum Polycephalum* behaviour.

The Case of Paris

Following a recent invitation from the Centre Pompidou and to illustrate this protocol in action on a famously top-down urban plan (see Haussmann's renovation of Paris), the GAN_Physarum is sent on a computational derive on the streets of Paris (Debord, 1956). While at first the visions conjured by GAN_Physarum have the disorienting quality of the non-human mind that conceived them, they also connect us with contemporary Paris at a more fundamental systemic level.

It is in fact known that contemporary cities share unique emergent behaviours and self-organising growth patterns with organisms like Physarum Polycephalum (Tero et al., 2010). Transport networks are ubiquitous in both urban and biological systems. Robust network performance involves a complex trade-off involving cost, transport efficiency, and fault tolerance. Biological networks have been honed by many cycles of evolutionary selection pressure and they develop without centralised control. This represents a readily scalable solution for growing networks in general and as part of a complex urban system. Therefore GAN_Physarum has the potential to evolve into a resilient urban planning model.

When the trained GAN_Physarum is deployed it actualises the capacities of Physarum Polycephalum in solving problems of urban re-metabolisation, carbon neutrality, energetic self-sufficiency and increased biodiversity. Most importantly these ambitious objectives are tackled within a non-human conceptual framework therefore opening up a whole new palette of potential design solutions in the urban realm. GAN_Physarum, in other words, offers the prospect of avoiding some of the common pitfalls of biophilic and biomimetic design protocols, namely the need for all-too-human metaphorical interpretations, as in the case of “urban forests”, or reductionist abstractions, as found in most “green networks” proposals.

Following the typically distributed model of practicing research in the global pandemic reality of 2020, the Parisian derive of GAN_Physarum starts in the air-conditioned laboratories of the Synthetic Landscape Lab at University of Innsbruck. Here at a constant room temperature

of 20 degrees a living *Physarum Polycephalum* in its active plasmodium phase is made to hunt for nutrients within the sterile environment of a lab-grade borosilicate glass Petri dish. Initially the growth substratum consists of a 2% agar with oat flakes as locally condensed food sources.

The plasmodium's typical networked body began spreading within minutes. For better documentation the Petri dish is positioned on a backlit surface and a camera is held above by a tripod. The camera lens has a focal length of 50mm, and the resolution of the raw images is 4240 x 2832 pixels. One photo is taken each 60 seconds for a total of 5190 images. The typical experiment lasts for approximately 3 and a half days.

The frames are then further edited by inverting the original input image and then copying the original layer on top with the blend mode colour filter. For further clarity of detail, a drop of blue food colouring is added on the agar substratum.

Once combined into a video sequence these frames reveal the extraordinary morphogenetic process during which *Physarum Polycephalum*'s body transforms into an optimised network for nutrients distribution. The process starts with a searching phase during which the pulsating body branches out in all directions detecting food sources and their relative distribution and size. In this phase traces of actin are left on the substratum, constituting a form of embedded memory, *Physarum Polycephalum*'s own outsourced brain.

What follows is a phase of optimisation. Finely detailed branches emerge in the relevant areas of the Petri while other parts are abandoned. Eventually some of the branches grow in size and become thickening convoluted transportation arteries. However, the optimised configuration never settles. As the resources are consumed and their overall distribution changes in real time, *Physarum Polycephalum*'s morphology adjusts.

The scarcer the resources become the more accelerated the change and adaptation. At the tipping point *Physarum Polycephalum* is seen racing around the Petri in an attempt to find new sources with sufficient energy to sustain its searching effort. Once nothing is left it retreats, until all the remaining energies are deployed to create new fruiting bodies, thus commencing the next phase in *Physarum Polycephalum*'s uniquely elaborated life cycle. After several years of

experimentation, it still beggars the authors' belief how so much complexity of form and behaviours can emerge from a simple unicellular organism.

Over time, the authors and their research team have increased the complexity of the nutrients' mix. The pH of the nutrients is now controlled to maintain high values. A selective distribution of malt extracts, oats and Spirulina powder extracts is now precisely inoculated to act as attractor points while a triple biotic ointment works as repeller. Through this system of nutrients distribution, the research team can now directly "communicate" with, or transfer information to, the *Physarum Polycephalum*.

A satellite image of Paris, duly processed to extract information about its biotic layer (plants, grasses, rivers and other "wet" surfaces), is remapped on a grid. The points on the grid transfer the geo-data of corresponding latitude and longitude of the map. A 3D data matrix is compiled storing the density of biomass as a percentage value of a fully vegetated pixel. This is achieved by translating the sum value of the green pixels of the map for each 4 neighbouring cells within the grid to an average percentage based on the total value of all the green pixels of the selected image.

After computing the average biomass on the grid points, these percentages of density are translated proportionally into amounts of nutrients on the growth substratum of *Physarum Polycephalum*, with cell size of 3cm. *Physarum Polycephalum* is then introduced from a source point external to the grid. And while *Physarum Polycephalum* begins its long bio-computational process to define the spatio-temporal distribution of nutrients, the authors and their team can shift their attention to the machine learning technique Cycle GAN, and in order to refine its ability to detect the biologically grown characteristics of *Physarum Polycephalum* and its complex behavioural patterns.

GAN_Physarum: “La Derive Numerique”

cycleGAN is a machine learning technique that uses the training of image-to-image translation models without paired examples. A generative adversarial network (GAN) has two parts, the generator and the discriminator, engaged in an internal competition. The generator learns to generate plausible data. The generated instances become negative training examples for the discriminator. The discriminator learns to distinguish the generator’s fake data from real data. The discriminator penalises the generator for producing implausible results (Google Developers, 2019).

Depending on the training input, this process results in the transfer of key features from one set of images onto another, and vice versa. In this case, the domain of source images and target images refer to the slices of two actual input-images that belong to two different domains, the urban and the biological. We used this technique to transfer the behavioural patterns of the Physarum Polycephalum onto the urban structure of Paris. The objective is to investigate how its biological intelligence can be applied on different scales to reinterpret existing infrastructures and building distributions of Paris itself.

While time lapsing, as described earlier, captures Physarum Polycephalum at different developmental stages, Paris is analysed at different resolutions through remote sensing. The significance of adding a zero to any number (Eames, Charles, and Ray Eames. 1977) reveals itself as a multiplicity of urban structures and urban morphological patterns can be detected as visual information while zooming in on the Centre Pompidou from a wide frame including the entire centre of Paris.

By using the power of 10 as decreasing degree of magnitude, the protocol captures frames of Paris at 4 different resolutions. The largest city scale is a 10 by 10 km frame, including the entire circular Périphérique of Paris and centred on the site of the Centre Pompidou. While zooming in, further resolutions are registered, including a 1 by 1 km frame, showing the Centre Pompidou with its surrounding neighbourhood, a 100 by 100m frame, representing the structure

of the Centre Pompidou with the adjacent streets and squares, and finally, a 10 by 10 m frame, focussing on the mechanical systems forming the external envelope of the celebrated Parisian architectural machine.

When the neural network of a CycleGAN is trained at each of these urban resolutions to a corresponding behavioural pattern of living *Physarum Polycephalum*, the GAN_Physarum emerges. The algorithm learns to interpret Paris in a unique way at each resolution. During the training process the characteristics of the *Physarum Polycephalum* behavioural patterns are compared to the ones of Paris. Over several epochs the algorithm learns how to reinterpret *Physarum Polycephalum*'s behaviours in relationship to Paris' morphological structures, and vice versa. When several behavioural instances are tested and the results are combined in a video sequence, a bio-digital derive emerges, and with it an unexpected vision of Paris coming alive in the mind of GAN_Physarum (Figure 3.2.4).



Figure 3.2.4 Transformation of Parisian urban fabric based on the biological intelligence of the *Physarum Polycephalum*. The images illustrate the unfolding re-organisation at progressively higher resolutions of the urban fabric. Frame 1 starts at 10km square and frame 4 ends at 10m square.

As defined at the beginning of the chapter, this non-human cognitive process is underpinned by the unique architecture of the GAN_*Physarum* workflow. This is best described in four main phases:

- The first phase describes the preparation of the input images for training purposes. The dataset preparation is automated, slicing input images from both time-lapse and satellite source domains into equal tiles of 256×256 pixels in size. This phase also includes pre-processing the input data with custom colours and contrast adjustments. Such adjustments increase the recognisability of the distribution of detected structures in the satellite source in relationship to the biological one.
- The second phase is the training of the GAN_Physarum based on these input datasets. The model is trained to detect the structures in the satellite source in relationship to the biological one, so it can learn to project behavioural patterns to urban morphologies. During the training the algorithm runs 200 epochs, and the visualisation of the evolutions can be illustrated in a browser window showing the learning process (loss function) of the algorithm.
- At this stage, the model is sufficient for generating plausible slices in the target domain. Subsequently the trained algorithm is tested. During this phase, the GAN_Physarum projects an input image in the biological domain A to an image in the urban domain B, and vice versa. Several cached models from the training phase can be loaded at this stage, thus tracking the self-evolution of GAN_Physarum.
- The fourth and final phase in the GAN_Physarum workflow refers to the combination of the output slices. This process is also automated. The algorithm uses the resulting output tiles from the testing algorithm, and combines them to a final image, using an overlap between the image tiles to get clean transitions in the combined output image.

Cities are dynamical systems that react to a variety of external resources' distributions and adapt by changing their morphology over time. Despite the huge scale difference, they appear remarkably similar, from the systemic point of view to a living, single-celled Physarum Polycephalum.

Both undergo constant transformations to optimise their overall performance. This aspect of transformation over time is accounted for in GAN_Physarum. This however requires multiple training sessions at each scalar resolution, since every scale has different structures of detail that can be interpreted. This is the case for both Paris and Physarum Polycephalum.

This process offers an unprecedented opportunity for a holistic analysis of the relationship between urban patterns and biological intelligence. Such analysis has widespread application. In order to validate such assumption and test the scalability of the GAN_Physarum protocol, the authors and their practice ecoLogicStudio have collaborated with UNDP on a dedicated research project titled DeepGreen.

DeepGreen, the Case of Guatemala City

In this project the authors have been testing the applicability of the GAN_Physarum workflow as a green planning interface. Its key feature is to combine scalability, a necessary quality of any sophisticated planning application, to design versatility. In other words, the expanded DeepGreen protocol ought to be:

- Open to multiple input so that urban stakeholders can interact with several layers of data and appreciate the effects of their hypothesis
- Time based, to enable all stakeholders to appreciate the effects of new policies and strategies systemically
- Visually compelling, thus enabling all stakeholders to visually appreciate the simulated urban form across several orders of scale.

The design scenarios, which emerged from the study, suggest that a key remit for DeepGreen is to help breaking the currently uneven distribution of resources to promote the evolution of restorative urban systems. As previously observed, this process often implies questioning

traditional planning concepts such as zone, boundary, scale, typology and program. Such outdated notions constrain the emergence of a truly systemic approach to urbanisation, one that recognises the nature of contemporary cities as complex dynamical systems and their interconnectedness with the larger Urbansphere.

This issue is most evident in the case of Guatemala City (Pasquero, Poletto, 2019). Guatemala City is situated on a complex and highly unstable terrain surrounded by mountains and volcanoes, some of which are still active. Its ecosystems, originally very rich in biodiversity, are now made fragile by unchecked urbanisation and given its climatic zone, the effects of climate change.

In Guatemala City this scenario is exacerbated by a serious lack of waste management. The Guatemala City garbage dump is the biggest landfill in Central America containing over a third of the total garbage in the country. Ninety-nine percent of Guatemala's 2240 garbage sites have no environmental systems and are classified as "illegal". Confronted with this scenario, the authors have come to realise that only a design methodology powered by big data gathering and the production of ad hoc algorithmic design scenarios can deal with such complexity and level of informality.

The DeepGreen protocol facilitates the creation of an interface between bottom-up processes of self-organisation, such as the many local waste recycling activities that are emerging out of necessity in the areas closer to the dumping sites, and the strategic decision making that occurs at municipal, national and international levels. The aim is to find new synergies and direct investments where and when they have the most potential to engender positive change.

In DeepGreen, the protocol to generate the urban datasets for GAN_Physarum is expanded in order to read and process several kinds of input data. As described at the beginning of this chapter it involves input data reading, biotic-abiotic analysis and network systems analysis.

In Guatemala City the authors refer to 3 different kinds of remote sensing data: land survey (at a resolution of 10m), Digital Elevation Models (at a resolution of 30m from the NASA database) and GIS vectorial data from the Open Streep Map project. These datasets are processed at a resolution of 1m over a frame of 16km comprising the entire city centre and several peripheral neighbourhoods.

Municipal, local and informal waste disposal and recycling sites are mapped, and their location marked. The existing road network is also mapped, and all potential sources of waste are located over it. Two sets of path systems are then computed: local path systems connect all waste sources with the closest dumping sites. Municipal path systems connect all dumping sites with six proposed municipal recycling centres. All paths are thickened, and colour coded depending on the amount of waste that travels on each of their branches. The process is repeated for different kinds of waste, organic, metal, paper and plastic. The emerging diagrams are fed to GAN_Physarum as urban datasets.

Two radical visions define the case of Guatemala City. On the one hand the waste infrastructure appears as a biologically active, convoluted and highly differentiated body, capable of sorting, transporting and re-metabolising the urban waste into nutrient and raw matter. On the other, GAN_Physarum reimagines Guatemala City as a networked body gently suspended over a wild substratum of proliferating biological life.

Once shared with a wider group of stakeholders these visions have triggered a more concrete set of proposals among which two are finding significant traction. A re-wilding plan to foster new coexistence between human and urban wild animals, and an urban agriculture plan proposing a method to guarantee food security and recycle organic waste while employing the rural population currently migrating to the city of Guatemala.

What matters to the authors is that both proposals are sensitive to local conditions while effecting international power relationships. For instance, the migrating birds populating the green areas of Guatemala City migrate to and from Canada. Therefore, investments in urban re-wilding will have benefit in the biodiversity of Canada too. Migrant workers cross the city on their way

to the US-Mexico border. Urban agricultural plans could retain rural workers alleviating the pressure on both Mexico and the US. Such synergies have the potential to channel significant international funds to local projects improving the life of citizens of Guatemala City.

BIT.BIO.BOT.

The application of DeepGreen to several urban design case studies has provided new conceptual and spatial frameworks to imagine a new kind of architecture. The project BIT.BIO.BOT. is one of the authors' most significant recent actualisation of this new paradigm and is better described as a collective experiment in biotechnological architecture. The driving principle for its design development is simple: if we, collectively, transform air pollutants and water contaminants into highly nutritious aliments, there will be fewer opportunities for unbalanced viral ecologies to exploit unsustainable food supply chains and polluted atmospheres to reach our organism and cause us harm.

The authors and their research partners, the Synthetic Landscape Lab at Innsbruck University and the Urban Morphogenesis Lab at the Bartlett UCL, were invited to participate in “How will we live together?”, the 17th International Architecture Exhibition, La Biennale di Venezia, curated by Hashim Sarkis, held in Venice from May 22nd to November 11th, 2021.

Within the “As New Households” section of the Corderie dell’Arsenale, the team built a 1:1 scale immersive experiment in the domestic cultivation of the urban microbiome. The experimental space is designed to test the coexistence between human and non-human organisms in the post-pandemic Urbansphere. The installation is an urban laboratory that combines advanced architecture with microbiology to build an artificial habitat, managed by a collection of systems which enable the cultivation of microalgae in the urban realm (Figure 3.2.5).



Figure 3.2.5 BIT.BIO.BOT. installation at the Corderie dell'Arsenale, Venice. Venice Biennale 2021. View of the bio.Curtains and the vertical algae garden.

The core biological mechanisms of BIT.BIO.BOT is the process of photosynthesis, powered by the sun and by the metabolism of living cultures of *Spirulina Platensis*, single-celled microbes that are often referred to as blue-green microalgae, and *Chlorella SP*. These living organisms are among the oldest on Earth and have developed a unique biological intelligence

that enables them to convert solar radiation into actual oxygen and biomass with unrivalled efficiency.

This advanced architectural system is the result of 10 years of bio-digital design research, developed by ecoLogicStudio and combining computational design strategies (BIT) with proprietary fabrication techniques (BOT) to implement a collective microbiological cultivation protocol (BIO).

BIT.BIO.BOT is composed of three fluidly interconnected systems that embody the fundamental architectural environments of a future dwelling: the Living Cladding, the Vertical Garden and the Convivium. The Living Cladding re-defines the limits between human and non-human realms and between architectural indoor and outdoor. It is composed of ten PhotoSynthEtica curtains. The unique version unveiled at the Corderie features a morphological pattern inspired by the surrounding brick walls, highlighting the microbiological nature of the Venetian architectural fabric. Furthermore, its articulation increases the interaction between micro-algae growth in the bio-gel medium, and the environment, as well as their screening and shading potential. Each curtain is 3 metres high and 1 metre wide, and features 35 metres of digital welding, which forms a cavity capable of containing 7 litres of micro-algae cultures.

The Vertical Garden creates a thick buffer zone located between the Living Cladding and the Convivium, dedicated to an intensive model of vertical algae farming. On a 3-metre tall and completely reversible stainless-steel structure, it hosts 15 BioBombola, the proprietary domestic algae garden system developed by ecoLogicStudio in response to the challenges of the first Covid-19 lockdown, in Spring 2020.

Each unit of Vertical Garden, made of lab-grade borosilicate glass and 3D printed bioplastic components, hosts 10 litres of micro-algae cultures in a highly efficient growing medium. Algae can be independently harvested from each unit several times per week to collect up to 100 grams of biomass, which is the daily recommended protein intake of a family of four. While active in production, the Vertical Garden is able to absorb CO₂ at a rate equal to three large mature trees, providing a clear path to carbon neutrality in architecture.

The Convivium is a space for sharing and for collective experimentation on the future of food. It takes the form of a 2×2 metre table, which hosts 36 unique pieces of crystal glassware designed to encourage experimentation in the consumption of the freshly harvested *Chlorella* and *Spirulina* cells, both of which are among the most nutritious organisms on Earth.

The crystal glassware is designed by ecoLogicStudio and 3D printed by Swarovski with its ground-breaking glass printing technology. Each piece is made of delicately fused glass layers—arranged in a matrix that algorithmically follows the morphogenesis of micro-algae cells, thus generating a variety of visual patterns. These will offer a multiplicity of opportunities to observe, transform and taste microalgae as part of a new culinary landscape (Figure 3.2.6).



Figure 3.2.6 BIT.BIO.BOT. installation at the Corderie dell'Arsenale, Venice. Venice Biennale 2021. Detail of the 3D printed crystal glassware serving one shot of Chlorella super-drink.

The entire installation, as well as the individual systems, are fully reversible. At the end of the Architecture Biennale, in November 2021, each unit will become an educational algae garden.

AirBubble

In Spring 2021, the authors and the ecoLogicStudio team built AirBubble with the ambition of bringing to life the world's first biotechnological playground to integrate air-purifying micro-algae.

The project aims to demonstrate the untapped value in bringing the bio-intelligence of natural systems into cities, turning buildings into living machines that produce energy, store CO₂ and clean the air (Figure 3.2.7).



Figure 3.2.7 AirBubble air purifying biotechnological Playground. Warsaw, Poland. External view by night.

AirBubble creates a purified microclimate for children to play in, a true bubble of clean air in the centre of Warsaw (Poland). The project is located within the public green space outside of the Copernicus Science Centre (Centrum Nauki Kopernik), a site which will also host a dedicated exhibition illustrating the design innovation behind the invention of AirBubble. The

playground integrates the Photo.Synthetica technology for the advanced integration of photosynthesis in the built environment.

According to the World Health Organization (WHO), air pollution is the biggest global health threat. Warsaw was selected as the first test site for this project as it is one of the most polluted cities in Europe. In this context AirBubble invents a new architectural typology. It incorporates a cylindrical timber structure wrapped in an ETFE membrane protecting 52 glass algae reactors. This creates a real urban algae greenhouse. The space is equipped with ropes, foot pumps and bouncy spheres, and can function as both playground and outdoor classroom. The white bubbling noise of the algae gardening system masks the surrounding urban noise to provide a calming atmosphere in which to play and interact.

The filtering process is enhanced by the architectural morphology of the playground structure. The ETFE membrane—an evolution of the Photo.Synthetica urban curtain system presented in Dublin in 2018 by ecoLogicStudio—controls the microclimate inside AirBubble. The inverted conical roof membrane further stimulates the air recirculation and natural ventilation, which in turn keeps the play area clean.

The AirBubble monitoring system integrates urban air pollution sensors and is connected to a data processing platform capable of comparing measurements in real time and of highlighting the Air Quality Index for six core pollutants: fine particulate PM_{2.5} and PM₁₀, ground level Ozone (O₃), Nitrogen Dioxide (NO₂), Sulphur Dioxide (SO₂) and Carbon Monoxide (CO). AirBubble is capable of absorbing 97% of the nitrogen and 80% of the particulate matter in the air.

Data collected in the period between May and August 2021 shows concentrations of PM_{2.5} within the playground have fallen well within the recommended WHO limits (green zone, AQI below 20).

The peak reduction rate is an impressive 83%. This figure has been calculated by comparing readings from a pollution sensor located outside AirBubble with real-time data feeds from a monitoring device placed inside. The monitoring phase will continue throughout the

autumn to verify these promising achievements over a longer period of time, under different climatic conditions and patterns of use. Over the next few months, AirBubble will become a unique urban laboratory, a test bed of applied biotechnology and its application in tackling air pollution and in mitigating its effect on children's health.

The AirBubble hosts 52 large bioreactors in borosilicate glass which contain 520 litres of living green *Chlorella* SP algae cultures that can filter a flow of polluted air of 200 litres/minute. While the liquid medium washes particles, the algae actively eat the polluting molecules as well as carbon dioxide to then release fresh clean oxygen. The purifying process is powered by solar energy and children's playfulness. Kids can interact by jumping on four water foot pumps positioned on the ground while balancing on the bouncy bubbles and the internal rope system. In other words, the playground needs two sources of power: solar energy and kids' instinctive drive to explore and to play. These constitute the inexhaustible and renewable fuels of the AirBubble that can be obtained effortlessly. The AirBubble is the trigger of a process that can only grow and multiply its beneficial effects towards future generations (Figure 3.2.8).

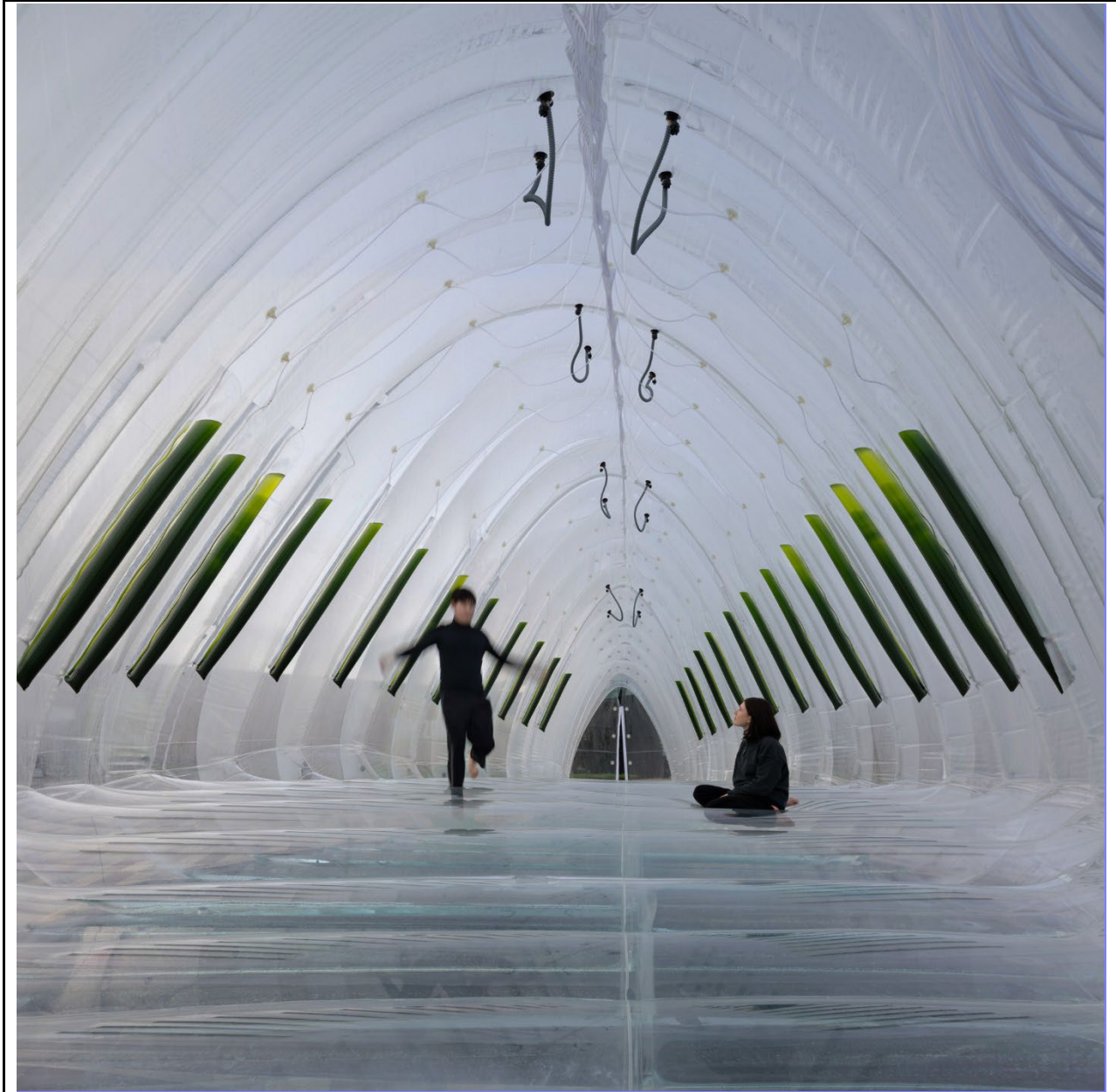


Figure 3.2.8 AirBubble carbon capturing eco-Machine. Green Zone COP26, Glasgow.

Conclusion

It is known that contemporary cities share unique emergent behaviours and self-organising growth patterns with organisms like *Physarum Polycephalum* (Tero et al., 2010), therefore the DeepGreen method has the potential to evolve into an effective urban planning model.

At its core lies the potential to capture the proven intelligence of *Physarum Polycephalum*, emergent, distributed and embodied, to design cities capable of searching for the opportunities of co-evolution within the expanded urban landscape, able to find untapped resources while minimising the expenditure of energy required to accomplish these fundamental survival tasks.

This unique perspective is proving critical to the conception, engineering, and actualisation of a new kind of biotechnological architecture with transformative powers in terms of urban health and wellbeing. An architecture made by humans, for both human and non-human citizens and planned by a new form of biomorphic intelligence.

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